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### Anthropogenic Impacts on the Longitudinal Gradient of Nutrients in the Little Bear River

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## Chapter 3

# Anthropogenic Impacts on the Longitudinal Gradient of Nutrients in the Little Bear River

[by] Jason Fuller

## SUMMARY

I measured the anthropogenic impacts from land use on nutrient concentrations along the Little Bear River in Cache Valley, Utah. Water samples from twelve stations along the Little Bear River were collected and analyzed using an auto analyzer in order to determine conductivity and concentrations of total nitrogen, total phosphorus, soluble reactive phosphorus (SRP), ammonia ( $\text{NH}_3$ ), and nitrate ( $\text{NO}_3^-$ ). Samples were collected at stations thought to reveal anthropogenically influenced nutrient loading. Some of the anthropogenic land usages that potentially impact the nutrient concentrations include agricultural land use, urban land use, Hyrum Reservoir, the Trout of Paradise fishing reserve located near the town of Paradise, and the Wellsville Wastewater Treatment Plant. Specific conductivity measurements indicated a 172 percent increase in ions from the headwaters to the lowest site sampled, near the confluence with Cutler Reservoir. My study indicated that total nitrogen was significantly increased by anthropogenic land use, with nitrate increasing from  $115 \mu\text{g N L}^{-1}$  in the headwaters to  $1260 \mu\text{g N L}^{-1}$  in the lowland agricultural areas. Total phosphorus (TP) did not appear to be influenced by anthropogenic land use above Hyrum Reservoir: However, below the reservoir concentrations reached  $60\text{--}75 \mu\text{g P L}^{-1}$ , above Utah threshold criteria of  $50 \mu\text{g L}^{-1}$ . Total nitrogen: total phosphorus ratios indicated that phosphorus was potentially the limiting nutrient at three of the twelve stations including the Trout of Paradise fishing reserve. The dissolved inorganic nitrogen (DIN): TP ratio indicated that phosphorus was the limiting nutrient at each of the stations except Station 8, which is located below Hyrum Reservoir. These findings highlight the influence of anthropogenic land use on the Little Bear River, within the framework of the Serial Discontinuity Hypothesis (Ward and Stanford, 1995).

## INTRODUCTION

The Little Bear River (LBR), located in northern Utah, starts in the mountains south of Cache Valley (See site map in executive summary). Our study area ranged from a first order stream in the mountains a third order stream in Cache Valley. The river runs through the valley and has significant anthropogenic impacts including agricultural use, reservoirs, cities, water treatment plants, and Hyrum Reservoir which is located near Hyrum, UT. These human uses likely affect the physical and biological aspects of the river and may cause nutrient enrichment which can increase nutrient loads of a riverine system resulting in eutrophication; defined as extreme productivity (Dodds 2010). Eutrophic environments can provide a very displeasing site for many people in the valley and may also result in negative impacts to the water quality. My study helps determine how these anthropogenic land uses may be causing the nitrogen and phosphorus concentrations to change in the LBR. It will also help provide an understanding as to whether the River Continuum Concept (RCC), the Serial Discontinuity Hypothesis (SDH), or both apply to the behavior of the Little Bear River.

The RCC describes patterns of ecological processes that change as a result of the intrinsic alterations to rivers as they grow in size and move downstream (Urbaniak et al. 2012). These changes occur naturally in many rivers throughout the world. Specific conductivity, a measure primarily of major ions like calcium and carbonates, should increase with downstream movement caused by weathering of minerals in the watershed (Kratz et al. 1997). It is expected that as the stream order increases in the LBR, the amount of nutrients in the river will increase, perhaps exceeding the general increase in specific conductivity.

It is also possible that the amount of nutrients in the river could decrease between the inlet and the outlet of Hyrum Reservoir due to deposition of the nutrients (Urbaniak et al. 2012.). This process could have important implications for stream reaches below Hyrum Reservoir and is best described by the SDH (Ward and Stanford, 1995). The reservoir is yet another factor that could affect the nutrients within the LBR.

The ratio of nitrogen to phosphorus is an important index to measure, as these nutrients are major factors that control primary production and heterotrophic activity in many ecosystems (Dodds 2010). The Redfield Ratio is the ratio of carbon: nitrogen: phosphorous when a system has balanced growth. The molar ratio of N: P in phytoplankton (we did not measure carbon in this study) is typically 16:1 (Dodds 2010) and 7.3:1 in weight units. By understanding the ratio of nitrogen to phosphorus in a river one can predict which nutrients may be limited and will also be able to verify which anthropogenic factors may be impacting the nutrients within the river.

The nutrient load is subject to variation throughout different seasons of the year (Billen et al. 2007). In Cache Valley it is typical to have higher flows in the spring due to runoff from the mountains surrounding the valley. This runoff often provides a surge in the nutrient load and many of these nutrients are stored in soils. These stored nutrients are periodically released into the river throughout the year. A similar study showed that soluble reactive phosphorus (SRP) had the highest concentrations during the summer months while approximately 92 percent of total phosphorus (TP) was found in the river between fall and spring (Bowes et al. 2003). Obviously these concentrations may vary due to differences in locations but it is important to understand that these nutrient loads may vary throughout the year as well. For my project, I was very limited on time and was only able to observe the nutrient concentrations for one day of the year on September 29, 2012. Any observations from this experiment are subject to change throughout the year but these observations should, in fact, give us a good perspective on how the nutrient concentrations change longitudinally due to anthropogenic use of the land during the active growing period for the algae and other organisms in the river.

The main objective of my project was to determine if anthropogenic land use along the Little Bear River continuum was correlated with increasing gradient in the concentrations of phosphorus and nitrogen as stream order increases. The study also allowed me to determine if the ratio of N: P changed along the gradient. These ratios can ultimately help us decide if the change in nutrient load is due to natural causes explained by the river continuum concept, or if the anthropogenic land use is indeed a major factor in the source of nutrients found in the river (Harding et al. 1999).

## FIELD STUDY AND METHODS

Samples were collected from twelve sample sites along a continuum of the Little Bear River (See site map in executive summary). Eleven of the stations were selected based on ease of accessibility and to adequately represent the different stream orders of the river. We wanted to represent many of the anthropogenic land uses that could possibly impact the nutrient concentrations in the LBR. One of these anthropogenic impacts included White's Ranch Fishing Preserve, which is located at river kilometer 22.4 and provides a large amount of water to the LBR. Water samples were consequently taken from White's water which enters the LBR just upstream from Station 5. Other notable anthropogenic impacts within the LBR watershed include agricultural land use, Hyrum Reservoir, urban land use, and the Wellsville Municipal Sewage Lagoons. Hyrum reservoir is located between Stations 6 and 7, the Wellsville sewage lagoons are located just upstream from Station 9, and a large portion of the land along the river below Hyrum Reservoir is utilized for agricultural use.

Before sampling water from each station, twenty-four Nalgene bottles were acid-washed to reduce contamination. Two replicate bottles were used to collect unfiltered water for "total nutrients" and two replicate bottles for "dissolved nutrients" for each station. Glass fiber filters (GF/F; 0.7  $\mu\text{m}$ ) were also rinsed with acid in preparation for the sample collection. An acid-washed syringe filtration apparatus and glass fiber filter was used to filter two replicates for dissolved nutrients at each station. Before collecting filtered samples from each station, the filtration apparatus was rinsed three times with river water to avoid contamination. Each of the Nalgene bottles for each station was also rinsed with river water before collecting samples. A YSI meter was also used at each station to record specific conductivity. All samples were collected on 29 September 2012 between 9:00 and 17:00, placed in a cooler with ice while in the field, and then stored in a lab freezer until lab processing was conducted.

The nutrient samples were analyzed in Dr. Michelle Baker's Biogeochemistry Laboratory at Utah State University. The "total nutrient" samples were analyzed for total nitrogen (TN) and total phosphorus (TP) following persulfate digestion. The "dissolved nutrients" samples were analyzed for soluble reactive phosphorus (SRP) and dissolved inorganic nitrogen (DIN) which is comprised of ammonium ( $\text{NH}_3$ ) and nitrate ( $\text{NO}_3^-$ ). Reagents were prepared for each sample and each sample was analyzed using an auto analyzer. A spectrophotometer was also used in class to analyze prepared samples for total phosphorus. The results from the spectrophotometer showed signs of contamination. Contamination could have occurred due to a problem with the reagent or because of a lack of experience from the student analysts. The results from the spectrophotometer were consequently not used in the analysis of the data.

Ratios of nitrogen and phosphorus for the LBR were calculated using two different methods. First, I used the common TN:TP ratio (Redfield ratio). However, Morris and Lewis (1988) calculated the minimum relative error (MRE) between results from nutrient addition bioassays, and for various ratios including TN:TP and DIN:TP and they determined that DIN:TP was a better predictor of whether N or P would limit algal growth than the more commonly used TN:TP. This suggests that the DIN: TP ratio more accurately determines which nutrients are limiting within a body of water (Morris and Lewis 1988). The TN:TP ratio tends to overestimate nitrogen available for biotic uptake (Morris and Lewis 1988).

For the TN:TP ratios I used the MRE criteria outlined by Healey and Hendzel (1980) to determine nutrient deficiencies in phytoplankton. I converted the molar ratios that they used into weight ratios. These values were used to determine which nutrients were limiting along the LBR continuum. For the TN:TP ratios phosphorus limitation occurs when the weight ratio exceeds 9.0:1. Weight ratios between 4.5:1 and 9.03:1 indicate a combination of both nitrogen and phosphorus limitation, and a weight ratio smaller than 4.5:1 indicates nitrogen limitation (Healey and Hendzel 1980).

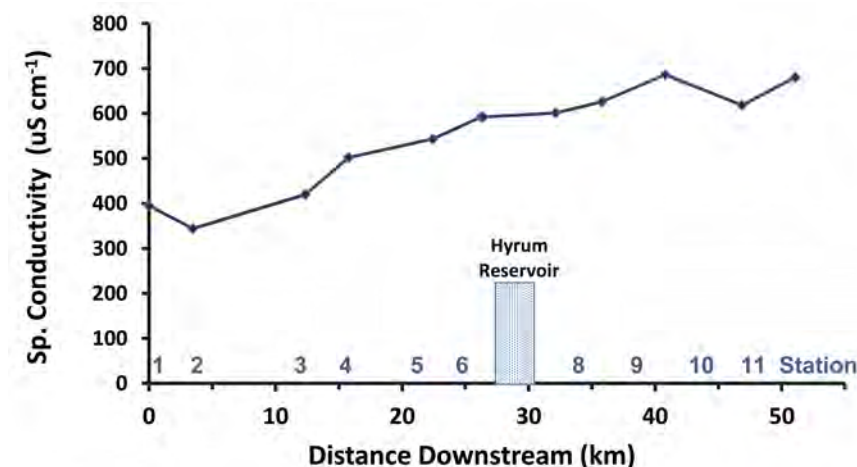
The MRE lines calculated by Morris and Lewis (1988) were used to analyze the DIN:TP ratios. Weight ratios greater than 4:1 indicate phosphorus limitation, weight ratios between 4:1 and 1:1 indicate co-limitation by both phosphorus and nitrogen limitation, and weight ratios below 1:1 indicate nitrogen limitation (Morris and Lewis 1988).

Anthropogenic land usage was calculated by Chance Broderius (2013; this report) using ArcGIS. The catchment area for each station was calculated and separated into different land use categories. Anthropogenic land use was categorized as urban land as well as irrigated, non-irrigated, and sub-irrigated agricultural land areas. Areas were calculated for each of the anthropogenic land use categories and then divided by the catchment areas for each station. This resulted in the percent of anthropogenic land use for each of the eleven stations.

## RESULTS

### *Specific Conductivity*

Figure 1 shows how specific conductivity increased longitudinally along the LBR continuum. There was a 172 percent increase in the specific conductivity from the headwaters (Station 1) to the lower reach (Station 11) of the LBR. This suggests that the concentration of major ions within the river increases downstream.



**Figure 1.** Specific conductivity ( $\mu\text{S cm}^{-1}$ ) of the Little Bear River continuum vs. distance in kilometers downstream on September 29, 2012. Station numbers are shown in blue above the x-axis. Specific conductivity is a measure of the concentration of ions within the river.

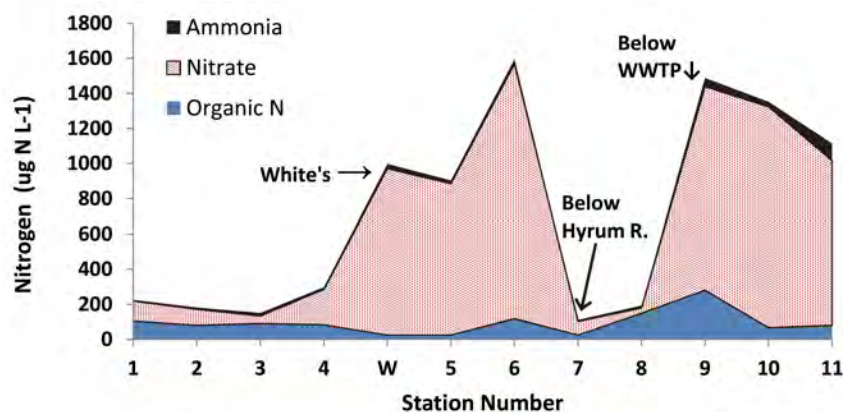
### *Components of Total Nitrogen*

Total nitrogen (TN) increased greatly down the Little Bear River continuum (Figure 2; Appendices). TN increased from 150-226  $\mu\text{g N L}^{-1}$  in the mountainous sites (Stations 1-3) but reached over 1300  $\mu\text{g L}^{-1}$  in the lowland agricultural areas. The main component of TN within the LBR was nitrate which reached a

concentration of  $1450 \mu\text{g L}^{-1}$  at Station 6. TN increased greatly first at the convergence of the White's Ranch Fishing Preserve, located at 22.4 km downstream from Station 1, and just upstream from Station 5. Mean nitrate and TN concentrations in the canal draining the fishing preserve were  $946$  and  $1008 \mu\text{g L}^{-1}$ , respectively. Nitrate continued to increase until the river reached Hyrum Reservoir between Stations 6 and 7. It is possible that the collection at Station 5 (km 22.41) did not fully incorporate the nutrients entering from Whites, as the sample was taken on the west side of the river whereas the White's discharge enters the river only 30-m upstream on the east side. Mixing may therefore have not been complete within the river. The majority of the flow was coming out of the discharge canal, with little from the river itself.

There was a large decrease in nitrate below Hyrum Reservoir at Station 7. Although DIN decreased, there was a notable increase in organic nitrogen at Station 8 (Wellsville) the reservoir. Nitrate continued to increase rapidly in the lower reach of the LBR especially between Stations 8 and 9. The water treatment plant is located just upstream from Station 9 and is assumed to be the source of a large amount of this increase in nitrate. Nitrate showed the largest percentage increase of any nutrient from the headwaters to the lowlands (976 percent; Figure 3).

Ammonia wasn't affected as drastically by anthropogenic land use in the LBR watershed as the nitrate concentrations. Ammonia made up only a small portion of total nitrogen concentrations (Figure 2). Ammonia increased little as the river progressed downstream, and then increased significantly below the Wellsville Wastewater Lagoon discharge (Figure 2), but the overall increase from the headwaters (Stations 1 and 2) to the lowland river (Stations 10 and 11) was 578 percent (Figure 3).

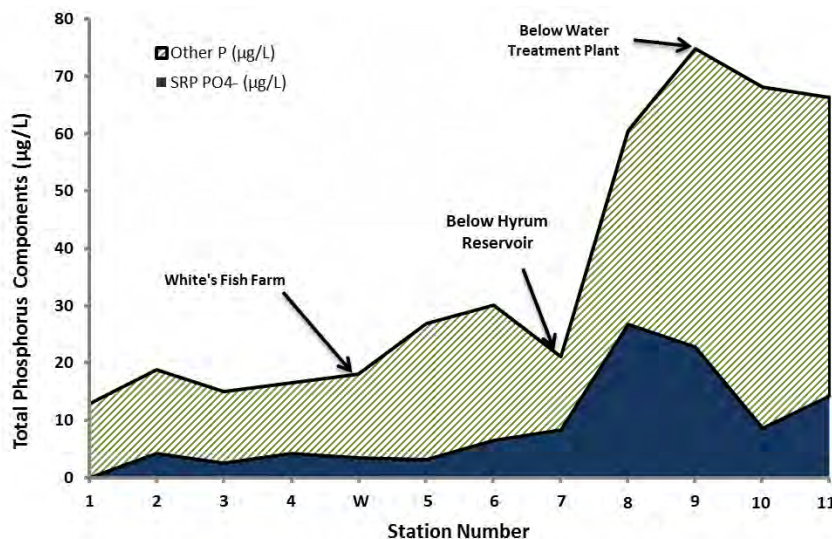
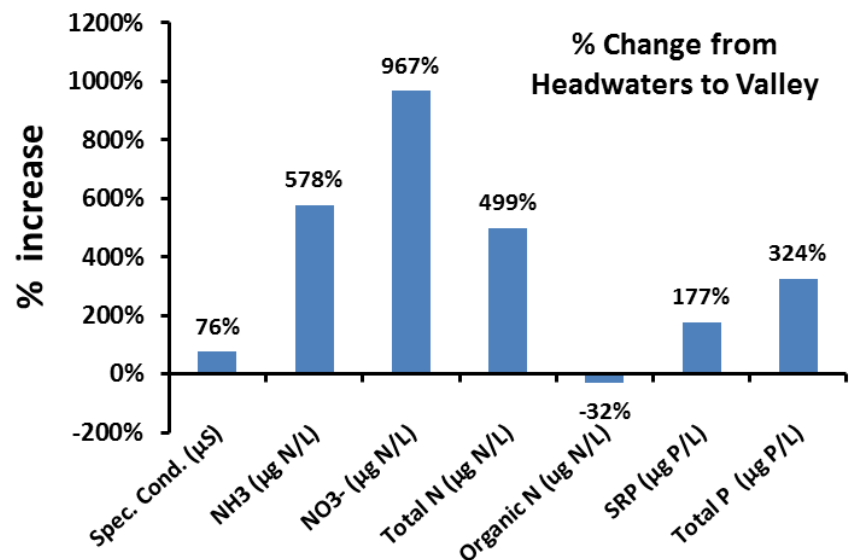


**Figure 2.** Organic nitrogen (Particulate + dissolved organic N), nitrate and ammonia concentrations from the headwaters (Station 1) to the lowlands valley reaches of the Little Bear River. The samples were collected on September 29, 2012.

### Components of Total Phosphorus

Total phosphorus (TP) first increased gradually along the LBR continuum and then increased significantly between the fishing reserve and Station 6 (Figure 4). TP then decreased between Stations 6 and 7 below Hyrum Reservoir. TP is comprised of soluble reactive phosphorus (SRP), dissolved organic P, and particulate phosphorus. The "other forms" of phosphorus were derived by subtracting SRP from the TP (Figure 4). Both SRP and "other forms" of phosphorus increased greatly after Hyrum Reservoir at Station 8, and then peaked below the water treatment plant at Station 9.

**Figure 3.** The percent of change in different nutrients from the average of Stations 1 and 2 in the headwaters to the average of Stations 10 and 11 in the agricultural section (and below the wastewater treatment plant). This percentage shows how most nutrients demonstrated a positive increase in concentrations between the headwaters to the valley.



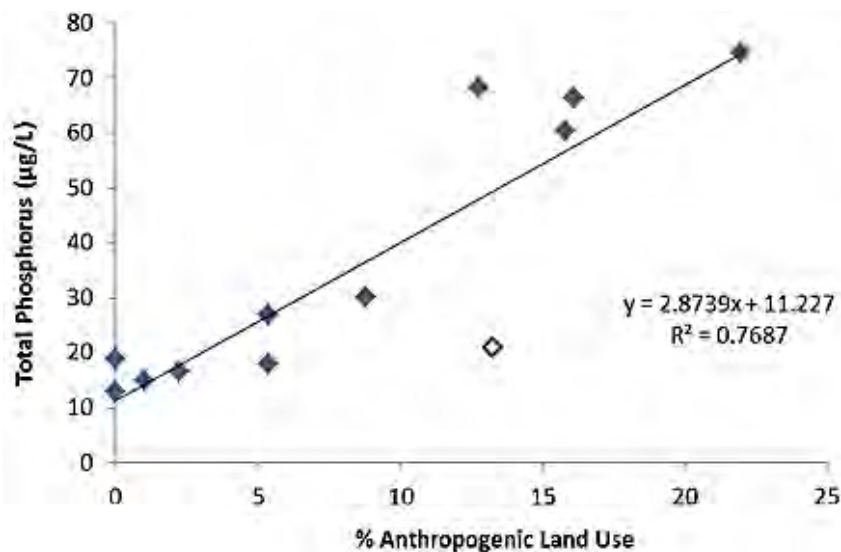
**Figure 4.** Breakdown of total phosphorus (top black line) along the Little Bear River (LBR) continuum in Cache County, Utah on September 29, 2012. Total phosphorus is comprised of SRP (soluble reactive phosphorus) and other forms of phosphorus. Note the significant decrease in total phosphorus below Hyrum Reservoir (Station 7), followed by a large increase in the reach between Station 7 and the town of Wellsville (Station 8).

Total phosphorus concentrations were correlated with the percent of anthropogenic land use surrounding the LBR ( $R^2 = 0.79$ ;  $p = 0.0002$ ; Figure 5). These statistics suggest that TP is significantly correlated with the percent anthropogenic land use though these results do not necessarily imply causation. Neither TN nor nitrate were significantly correlated with the percent anthropogenic land use of the land (TN:  $R^2 = 0.265$ ;  $p = 0.087$ ;  $\text{NO}_3^-$ :  $R^2 = 0.197$ ;  $p = 0.148$ ). The lack of correlation was likely due to the very large decrease in nitrate (and TN) below Hyrum Reservoir (Station 7).

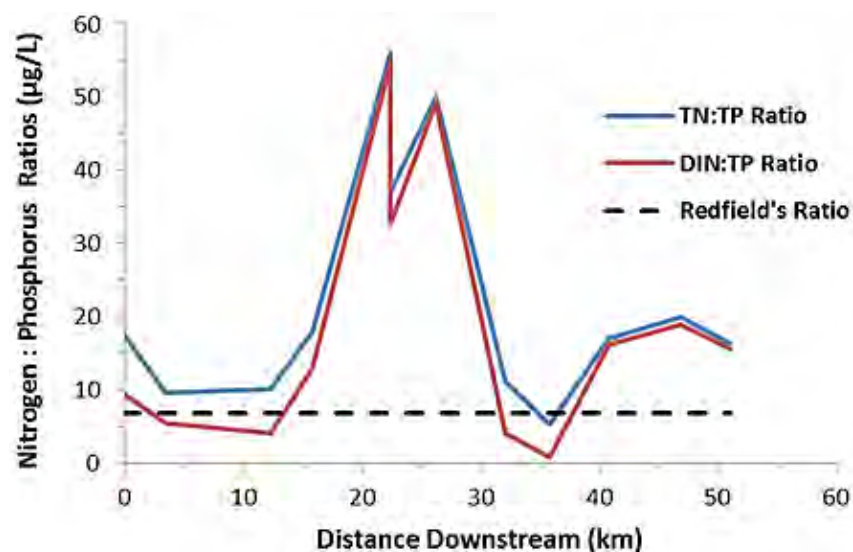
### N: P Ratios and Nutrient Limitation

Both the TN:TP ratio and the DIN:TP ratios indicated that algae would be phosphorus limited at most stations in the Little Bear River (Figure 6). The exception was Station 8 where the ratio suggested that N would be limiting: The mean TN:TP ratio there was 5.4:1 and the DIN:TP ratio was 0.72. However, the DIN:TP ratio frequently approached levels suggesting co-limitation of N and P.





**Figure 5.** Relationship between anthropogenic land use (largely agriculture) and total phosphorus concentrations along the Little Bear River on September 29, 2012. Land use in the watershed was derived from Broderius (Chapter 6 of this report). The hollow diamond is the Station below Hyrum Reservoir. Two replicates were taken at each station, but in some cases the variability was small and the points are superimposed on each other.



**Figure 6.** TN:TP ratios (blue line) and the DIN:TP ratio (red line) along the Little Bear River continuum from the headwaters (0 km) to the lowlands. These ratios are helpful in determining which nutrient is limited within the water. Redfield's ratio (dotted line) defines the standard ratio of N:P which is approximately 6.8:1 µg/L. Ratios above the Redfield ratio suggests that phosphorus is the limiting nutrient. DIN:TP is a ratio preferred by Morris and Lewis (1988) because it excludes forms

of nitrogen that aren't readily available for use to most organisms in the environment. At DIN:TP ratios below 1:1 N likely limits algal growth and between 1:1 and 4:1 co-limitation of N and P is expected.

## DISCUSSION

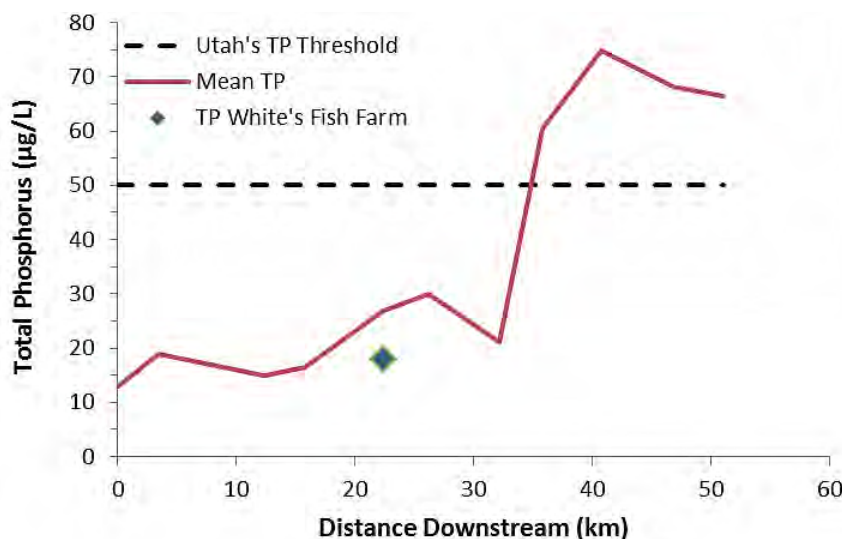
Total nitrogen and total phosphorus both increased longitudinally along the LBR continuum. TN and TP were affected by the various anthropogenic land usages along the continuum. As expected the water draining White's Fishing Reserve and the Wellsville waste water treatment plant provided significant increases in TN. However, these results weren't as clear in the TP data. The increase in TN at Stations 5 and 9 indicated that anthropogenic land use does appear to impact the nutrient concentrations in the LBR. The state of Utah has a threshold criteria set for the concentration of phosphorus which helps define whether or not a body of water is considered eutrophic. The current threshold is a concentration of 50 µg L<sup>-1</sup> for phosphorus (Rule R317-2, Utah.gov, 2012). This threshold is shown in Figure 7 for the LBR. Phosphorus concentrations exceeded the threshold at the four sites (Stations 8-11) below the town of Wellsville, suggesting that water downstream of Station 8 is eutrophic, according to Utah standards.



An in-depth bioassay was performed by Jared Baker (2013, this report) for the LBR continuum. He sampled water from Stations 2, 6, 7, and 10. I was able to compare my nutrient limitation results with Baker's bioassay experiment results and found that his results varied from mine. Baker found that a combination of both nitrogen and phosphorus were the limiting nutrients at Station 2. My results indicated that phosphorus should have been the only limiting nutrient at Station 2 suggesting that some of the TN measured was not bioavailable. The rest of the stations that Baker observed had similar results as mine, indicating that phosphorus was the limiting nutrient. Unfortunately, Baker didn't sample from Station 8 so a comparison of what happened below Hyrum Reservoir was not possible.

TN and TP concentrations along a continuum of the LBR suggest that hypotheses suggested by the SDH (Ward and Stanford, 1995) do hold true. Similar to the study by Urbaniak (2012) which took place in Central Poland, a significant decrease in TN and TP occurred below Hyrum Reservoir. We assume that this is due to many of the nutrients being deposited in the reservoir and trapped by Hyrum dam. Additionally, the very low discharges below Hyrum Dam allowed luxurious filamentous algae at the Station 7 reach (see photo in Executive Summary), and this periphyton may have also removed significant amounts of nitrogen and phosphorus from the water column.

Two factors in the research design confounded my analysis. First, on the day that we collected water samples we were notified by the waste water treatment plant that effluent wasn't being discharged into the LBR. Because of this we didn't expect a substantial increase in nutrients at Station 9. This wasn't the case, because a large increase in TN occurred between Stations 8 and 9. What caused this enormous increase in nitrogen? One hypothesis is that many of the nutrients from the waste water treatment plant infiltrate the hyporheic zone and in turn, have delayed releases of nutrients into the river. Comparing results of water samples taken when the wastewater treatment plant is releasing water to the LBR, with the results of water samples taken without an input from the plant would show how much of an increase in nutrient concentrations normally occurs at Station 9. Secondly, because of the restricted temporal analysis (one day!), I was unable to understand temporal changes in nutrient concentrations. I would suggest sampling the LBR during multiple time periods throughout the year to gain a better understanding of nutrient concentrations and loading.



**Figure 7.** Total phosphorus (TP) of the Little Bear River continuum vs. distance in kilometers downstream. Distance downstream begins with Station 1 at zero kilometers in the river headwaters. Utah's total phosphorus threshold of 50 µg/L is shown as the dashed line. Any measurement of TP greater than 50 µg/L is considered eutrophic and poor water quality.

## CONCLUSION

I feel that these results suggest that anthropogenic land use of the land along the LBR continuum indeed impacts the nutrient concentrations within the river. The serial discontinuity concept (Ward and Stanford, 1995) is adequately demonstrated along the LBR continuum, showing a disruption in nutrient trends caused by Hyrum Reservoir. It is unclear how much the hypotheses of the river continuum concept predict the nutrient concentrations along the LBR. However, conductivity concentrations may in fact fall in-line with its predictions.

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## APPENDICES

**Appendix 1.** Chemistry data along the Little Bear River Continuum Study, WATS 4510 2012 (Jason Fuller).

Station	Replicate	D.O. (mg/L)	Temp (°C)	Specific Cond. (µS/cm)	Ammonia (µg/L)	Nitrate (µg/L)	Total N (µg/L)	SRP (µg/L)	Total P (µg/L)	N:P (weight)	DIN:TP
1	A	6.8	12.2	395	5.1	111	218	bdl	13.8	15.8	8.4
	B				8.9	119	234	bdl	12.0	19.5	10.6
2	A	7.6	14.8	344	12.6	93	194	3.6	20.7	9.4	5.1
	B				10.0	89	170	4.7	17.0	10.0	5.8
3	A	8.1	15.9	420	8.4	43	159	3.1	14.9	10.7	3.4
	B				28.3	44	144	1.9	15.1	9.5	4.8
4	A	10.5	16.4	502	12.3	205	307	4.5	17.3	17.7	12.5
	B				9.9	201	287	3.8	15.8	18.2	13.3
Whites Fish Farm	A	NA	NA	NA	16.8	947	1002	3.2	18.1	55.4	53.3
	B				56.9	945	1013	3.6	17.9	56.6	56.0
5	A	10.1	15.9	543	17.3	860	1007	3.9	24.6	40.9	35.6
	B				20.5	861	988	2.3	29.2	33.8	30.2
6	A	9.2	16.6	592	35.9	1456	1534	7.4	27.9	55.0	53.5
	B				18.5	1443	1470	5.7	32.2	45.6	45.4
7	A	10.3	16.0	601	11.2	78	236	8.2	22.3	10.6	4.0
	B				5.4	77	235	8.3	19.8	11.9	4.1
8	A	9.1	14.7	626	12.6	31	349	32.9	61.2	5.7	0.7
	B				13.2	30	297	20.5	59.9	5.0	0.7
9	A	8.4	12.6	686	56.1	1160	1296	30.1	70.7	18.3	17.2
	B				42.7	1158	1255	15.5	78.9	15.9	15.2
10	A	8.7	11.8	618	22.6	1257	1376	12.2	72.2	19.1	17.7
	B				30.8	1259	1354	5.1	64.1	21.1	20.1
11	A	7.9	13.5	680	110.2	934	1076	9.5	65.0	16.6	16.1
	B				84.7	939	1081	19.1	67.7	16.0	15.1

NA- Not Available

bdl – below detection limits

DIN=NO<sub>3</sub>- + NO<sub>2</sub>- + NH<sub>3</sub>

**Appendix 2.** Site characteristics,  $\delta^{15}\text{N}$  values and areas and proportion of the watershed anthropogenically influenced (Broderius).

Station	Replicate	$\delta^{15}\text{N}$	Catchment Area (km <sup>2</sup> )	Anthropogenically affected land use* (km <sup>2</sup> )	Percent Anthropogenically affected land use*	Total N (µg/L)
1	A	2.4	15.4	0.0	0.0	218
	B	2.6				234
2	A	3.2	45.8	0.0	0.0	194
	B	3.1				170
3	A	5.1	162	2.0	1.2	159
	B	4.3				144
4	A	7.4	343	8.9	2.6	307
	B	7.7				287
White's Fish Farm	A	5.5				1002
	B	7.6				1013
5	A	5.4	387	17.3	4.5	1007
	B	5.9				988
6	A	8.4	454	45.2	10.0	1534
	B	7.4				1470
7	A	12.5	480	67.8	14.1	236
	B	13.0				235
8	A	13.0	503	92.6	18.4	349
	B	13.7				297
9	A	9.1	584	129.0	22.1	1296
	B	8.3				1255
10	A	5.9	599	141.3	23.6	1376
	B	6.4				1354
11	A	8.5	625	156.8	25.1	1076
	B	9.0				1081

\*Anthropogenically affected land use includes: irrigated agricultural land, non-irrigated agricultural land, sub-irrigated agricultural land, and land in urban development